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An Automated System for Global
Atmospheric Sampling Using
B-747 Airliners

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16. Abstract

The Global Air Sampling Program was initiated in 1972 to utilize commercial aircraft in scheduled service to measure atmospheric constituents.

A fully automated system, as designed for the 747 aircraft, is described. Airline operational constraints and data and control sub-systems are treated in detail. The overall program management, system monitoring, and data retrieval from four aircraft in Global service is described.

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SUMMARY

The Global Atmospheric Sampling Program - GASP - was a NASA program administered by the NASA-Lewis Research Center in Cleveland, Ohio. The program started in 1972 with a feasibility study and was followed by a design and installation contract which placed the first system in operation in late 1974. The active data collection phase of GASP ended in July 1979.

GASP was initially intended as a program to provide atmospheric data from altitudes and routes flown by regular commercial airlines and to determine the long-range effects of such aircraft on the troposphere and the lower stratosphere. A GASP installation consisted of up to 22 measurement instruments and control units and was carried aboard Boeing 747 aircraft to automatically collect, analyze, and record various concentration of gases, fluids, and particulates.

NASA-Lewis directly contracted several manufacturers to develop and build the individual sampling instruments. United Airlines was selected to design, procure, integrate, install, operate, and maintain the airborne GASP system. In turn, United subcontracted with Pan American Airways and Qantas of Australia to install, operate, and maintain GASP installations on some of their aircraft.

The following, final Contractor's report describes the overall hardware design and the software system development needed to accomplish GASP's goals. Major subsystems are identified, and additional references are provided for further detailed descriptions.

This report also spotlights important operation and maintenance concepts that commercial airlines must consider when undertaking programs of this scope. Recommendations are given to aid both government agencies and air transportation companies in such future projects.

This report does not discuss any scientific data or data records obtained by the GASP system, since this was a NASA responsibility.

INTRODUCTION

In the past decade, scientists and engineers have been increasingly concerned about man's effect on the environment. With the advent of supersonic aircraft, particular attention has been directed at the inter-relationship of high altitude aircraft operation and upper atmospheric chemistry. Two MIT studies on inadvertent climatic modification, due to man's high altitude aircraft operations, were conducted in 1970 and 1971. A Congressional report was completed in 1974 on potential climatic impact resulting from engine emissions of high altitude aircraft. All three reports emphasized the need for detailed measurements of atmospheric constituents in the upper troposphere and the lower stratosphere and also recommended continuous atmospheric monitoring to detect changes in atmospheric quality.

Therefore, in 1972, NASA-Lewis Research Center initiated a four-month feasibility study amongst three commercial airlines and one airframe manufacturer. The objective was to examine the atmosphere between 6 and 12 km using commercial aircraft as instrument platforms. Basic system concepts derived from the feasibility study were incorporated into a data gathering program which became known as the GLOBAL ATMOSPHERIC SAMPLING PROGRAM (GASP) (Ref. 1). Constraints to the program and system design included:

- No revenue space would be taken from either the passenger compartment or the cargo hold. Windows would not be blocked off with special probes.
- The system would not interfere with normal scheduled operation of the aircraft.
- No cockpit crew duties would be imposed beyond monitoring of a fault light and operation of an ON/OFF switch if the fault light appeared. The cockpit crew would, at all times, have control over system power.
- Limited servicing and maintenance would be performed on a non-interference basis, mostly overnight.
- All units must be packaged to accepted airline standards and tested to show aircraft environment compatibility.
- The aircraft would not be removed from service exclusively for system installation for any lengthy period of time. Kits could be installed in limited time increments during out-of-service periods scheduled for other purposes.

INTRODUCTION (Cont'd)

- Any equipment installed in payload or revenue areas would be subject to possible damage from passenger or cargo movements. Such equipment could also be off-loaded or made inaccessible for service because of revenue producing cargo.
- Because each participating airline would have an average of one aircraft of twenty outfitted with the GASP instrument package, and because there would be more than twenty stations at which an individual aircraft could stop for service and maintenance, it was clear that the GASP installation must require minimum dependency on normal airline routines and maintenance personnel. No special routing or specially trained and dedicated cockpit crew could be used.
- As the capital cost and the productivity of aircraft have increased, so have the costs for out-of-service time increased. Therefore, both modifications to the aircraft for GASP instrument installations and routing maintenance of the system had to be designed to span the minimum down-time.
- Primarily for reasons of safety, regulatory agencies required that the GASP installation meet the standards of other aircraft equipment. The instruments and other equipment must be secure, even in the case of an abnormal attitude or forced landing; it must not create any fire hazard or emit any poisonous gases; and it must not interfere with present aircraft installations.

After considering all of the above constraints and further considering the economics of operating certain aircraft, the Boeing 747 was selected as the carrier aircraft. It had sufficient volume in non-revenue compartments to contain the instrument package and it had the long-range capability for extended flights in the 6-12 km altitude range. The Boeing 747 also had world-wide usage on air carriers other than domestic airlines, and it already had many on-board systems which could be used to supply geographical, meteorological, and aircraft operational data (e.g. inertial navigation) to the GASP instruments package.

All units of the GASP system were packaged in airline standard cases using mounting rack and hold downs accepted by the industry. All units were modified to utilize standard aircraft 115VAC/400 HZ or 28VDC power and had to meet applicable airline industry standards for electromagnetic interference.

INTRODUCTION (Cont'd)

GASP systems were designed by the United Airlines Engineering Division for installation on a United 747 (December 1974), a Pan Am 747 (March 1975), a Qantas of Australia 747 (November 1975), a Pan Am 747SP (April 1976), and the NASA-Ames CV-990 (June 1976). The United 747 provided coverage for the contiguous United States and to Hawaii; the Pan Am 747's provided world-wide coverage; the Qantas 747 southern hemisphere coverage; and the NASA-Ames CV-990 provided special and dedicated coverage of unusual meteorological events.

While NASA supplied the airline-standard modified instruments and intra-unit air sampling pressurization system (i.e. unit-to-unit plumbing), United Airlines, as prime contractor, designed and supplied all other GASP system components. This report will emphasize the integration of the complete system, the installation of the system on the various aircraft, and the maintenance program established by United Airlines to support the GASP system.

OVERALL SYSTEM DESCRIPTION

The GASP air constituent measuring system was installed in the 747 airliner below the first class passenger floor near the nose wheel area between STA 160 and 400 (see Fig. 1). The entire system was forward of the existing avionics rack and can be divided into four functional categories: (1) the air sample flow system, which includes the sample inlet, the ducting, the pressurization system and the exhaust system to dump the sample airflow overboard; (2) the individual instruments for determining the concentration of the selected atmospheric constituents; (3) the data acquisition, management, and recording system; and (4) the pre-programmed automatic control for the entire GASP system.

Ducting from the air sampling inlet probe directed the air to the filters on the right side of the 747 for collecting particles, and it also directed air to the left side of the aircraft, where it was pressurized to 1 atmosphere and selected air constituents measured. Computer-controlled solenoid valves discharged the airflow overboard at either right or left ends of the ducting.

Most of the measuring and data acquisition and control equipment was located on the left side of the nose wheel well. The equipment was installed on specially-designed racks which were attached to existing aircraft structure. In close proximity

OVERALL SYSTEM DESCRIPTION (Cont'd)

to the GASP equipment were the existing avionics racks. This allowed for easy access and integration of the GASP wiring to the inertial navigation system and the air data system, both of which were necessary to provide supplemental aircraft related data to the GASP system. This location offered easy accessibility of the GASP System for inspection and maintenance. The space was not previously used except as storage for aircraft manuals (Qantas only).

AIR SAMPLE FLOW SYSTEM

The air sample for the GASP measurements required two separate inlets outside of the aircraft in order to measure both gases and particles. A separate inlet was needed to measure the size distribution of particles. Isokinetic sampling (probe inlet velocity equal to free stream velocity) was required to obtain an undistorted measure of particle size distribution. A single air inlet would not provide isokinetic sampling because the flow rate to the instrument package and filter collector varies under operating conditions. Also, flexibility was desired in the system to add instruments which would also vary the flow requirements. Both air inlets were covered at low altitudes and on the ground to prevent any contaminants from entering the air sample flow system.

Generally, unpressurized air was desirable to avoid interference with the constituent to be measured. However, a pressurized air sample was desirable for some measurements in order to achieve the necessary instrument sensitivity.

Air inlet probe. The two air sample inlets were mounted one above the other in a single strut, using a single probe cap unit with its associated actuator. The probe cap was anti-iced when extended. A sketch of this dual probe is shown in figure 2. The probe is shown in the capped condition. In flight, above sampling altitude, when the inlets are opened, the probe cap was rotated into the probe cap housing by an aircraft-type actuator and became flush with the aircraft skin. The housing was a pressure-tight box mounted inside the aircraft. The design drag at $M=0.92$ and at a 7.5-km altitude was 7 kg.

Air entered the gas sample probe through a 25-mm-diameter inlet. This probe also supplied air to the particle filter, which did not require isokinetic sampling. It was, however, important to reduce the air velocity to the filter to avoid loss of particles by impaction on the walls at bends in the ducting and to minimize pressure losses. Air in the 25-mm-diameter tube was therefore expanded through a diffuser into a 76-mm-diameter duct to reduce the velocity. Air to the gas sampling instruments was tapped from the expanded duct at the diffuser exit with a 12-mm-diameter probe.

AIR SAMPLE FLOW SYSTEM (Cont'd)

Air entered the outermost particle counter probe through a 6.9 mm-diameter inlet. This probe is 100-mm (about three times the boundary layer thickness) from the aircraft skin. Isokinetic sampling for the particle counter probe required a more sophisticated design than for the nonisokinetic gas sampling. The flow rate required by the particle counter of about 30 liters/min. results in an extremely small size inlet if inlet velocity were to equal the free-stream velocity of about 0.8 Mach. An inlet having about 6.9-mm-diameter was considered as small as practicable for particle sampling. These constraints resulted in the following design approach.

The sample air entering the 6.9-mm probe was expanded through a diffuser into a larger diameter tube to reduce velocity. A secondary probe of about the same size located in the low velocity region of the larger tube provided the proper airflow to the particle counter. The excess air caught by the primary inlet was exhausted at the rear of the expanded tube through a properly sized orifice, which required knowledge of the pressure at this location on the aircraft. A special static pressure tap was installed, and data were taken in the initial 747 flight. This information and the wind tunnel test results were used to size the exhaust orifice to give isokinetic sampling at nominal cruise conditions of 10.7 km altitude and free-stream Mach number $M=0.82$.

Air sample pressurization. Air to the gas sampling instruments that require sample pressurization was pressurized with a teflon-coated diaphragm pump. A flow rate of 14 liters/min. was maintained by the pump at 1 ± 0.007 atm. This pressure was held constant from 6 to 12 km by the pressure regulation system described in reference 2. A simplified flow diagram is shown in figure 3. Basically, a backpressure regulator controlled the pressure out of the pump to the instruments by bypassing excess air through it. An absolute pressure regulator, which contains a sealed bellows reference cell, supplied a constant reference pressure to the dome of the back-pressure regulator. This system was chosen to avoid possible contamination by passing sample air to the instruments through a regulator. Components of the pressure regulation system were contained in a flow control unit.

The pump was mounted in a separate unit which also contained relays and thermostats used for control and safety. Pressure switches protected the system from overpressure and underpressure. A pressure relief valve was used as a safety back-up to the overpressure switch.

DATA ACQUISITION AND SYSTEM CONTROL

All GASP system operations were controlled by a special purpose 8K memory computer. The simplified block diagram in Figure 4 shows the inter-relationship between the data acquisition and system control subsystem and the rest of the GASP installation and aircraft systems.

All major components of the data acquisition and system control were airborne type equipment. The processor, system control functions, and certain data acquisition functions were combined in a Data Management and Control Unit (DMCU). This unit was obtained by modifying a Data Management Unit (DMU) as used by several airlines. Most of the aircraft data acquisition was handled by a standard Flight Data Acquisition Unit (FDAU) as defined in ARINC Characteristic 573. The digital cassette recorder was the Digital AIDS recorder (DAR) used by several airlines for onboard data recording.

After power turn-on and system reset, the processor, upon receiving a signal for 6 km altitude, opened the air inlet and the vents, started the pumps, and set up the system for sampling. A sampling cycle was 60 minutes long, consisting of twelve 5-minute segments. A 16-second recording was taken at the end of each 5-minute segment. Alternate segments were periods in which the system was put into one of six different calibration modes. The calibration modes make possible a between-readings check of the instruments to enhance the confidence in each measurement. If one was available, a particle filter was exposed every third day. The exposure occurred at an altitude above 9.6 km for a normal period of 2 hours unless an earlier descent below 9.6 km was experienced. Normal system operation was interrupted only during insertion and retraction of the filter. In addition, whole air sample, for later measurement of chlorofluoromethane, was taken in level flight at altitudes above 9.3 km on every third day if a sample bottle was available. Normal system operation was also interrupted during the sampling process which involved purging the bottle with unpressurized air for 5 minutes prior to sealing the bottle.

As the aircraft descended below 6 km, the processor completed the instrument measuring cycle and shut down the GASP system by closing up vents and capping the probe. The processor then reset the entire system to be ready for the next flight.

The processor could also recognize certain major failures and modify the system set up accordingly. In case of major data acquisition or system control problems, a light went on in the cockpit requesting the flight engineer to deactivate the GASP system until it was checked out. If the air inlet did not open at 6 km, the flow system was not activated, but other measurements, such as water vapor and metrological data, were recorded.

Most of the system control time constants or trigger levels could be altered by a simple entry from a carry-on panel. This included parameters such as recording time, filter exposure time,

DATA ACQUISITION AND SYSTEM CONTROL (Cont'd)

particle count time, bottle sample purge time, record interval, sample, filter or bottle sample altitude, acceleration limits, etc. The carry-on panel also allowed inflight monitoring of the system during which an observer could completely take over system control to evaluate alternate control sequences without reprogramming the processor. The panel also displayed real time data readings in engineering units.

The program for the processor was on paper tape, and it could be electronically loaded into the processor memory on the aircraft using a carry-on loader/reader.

Data Acquisition. The processor also controlled data acquisition and data recording. Special records were taken at takeoff and landing to allow a determination of flight end points by latitude and longitude.

The data acquisition subsystem read data from the measuring instruments, and received supportive data from the flow system, including pressures and temperatures. Status information from the GASP system, including valve positions, failure flags, instrument identification signals, etc., were also recorded. In addition, aircraft flight data were collected at the time data was being read from the measuring instruments. Position, heading, and the computed wind direction and velocity were obtained from the inertial navigation system. Altitude, airspeed, and static air temperature were collected from the center air data system in the aircraft. Vertical acceleration information (an indication of turbulence) was taken from the aircraft flight recording system. Date and time were provided by a separate GASP clock-calendar unit. (Ref. 3). /

Vertical acceleration was always recorded as part of the normal data and, in case of severe turbulence (which was set in the processor at less than 0.8 g or more than 1.2 g), a special recording was taken. The processor interrupted normal sequences to take data when these acceleration limits were exceeded. All data which had been stored in the memory 8 seconds prior to the turbulence encounter was also recorded. The special recording continued for 60 seconds after the acceleration limits returned to within limits. Then acceleration was sampled 8 times per second.

All analog data was digitized, and digital data was reformatted by the data acquisition system under control of the processor and outputted to a digital cassette recorder. Analog parameters were typically digitized into a 12-bit word with an accuracy of 0.25 percent. The cassettes had a capacity for more than 6 weeks of data at the normal GASP recording rate. The cassette data was transcribed on the ground onto computer compatible tape, which provided the raw input data for processing at NASA-Lewis Research Center.

DATA ACQUISITION AND SYSTEM CONTROL

Data Acquisiton. (Cont'd)

There were 15 different modes of operation, the details of the program flow are as follows:

MODE 1 is generated by system power on and will preset all system functions to a closed up condition. It will self-test the processor, the data acquisition system and the recorder and then transfer to Mode 2.

MODE 2 is the preflight idle mode where the system will accept a tester input for transfer to ground test modes or, upon detection of an altitude above 6 km, it will go to Mode 3.

MODE 3 is the set-up mode, where, above 6 km altitude, the system opens up, starts the pump, self-tests the set-up conditions, and then goes through a 5-minute purge before entering Mode 4.

MODE 4 is the active sampling mode where five-minute intervals of data measurements are followed by alternating calibration measurements. A 16-second record is stored in the cassette at the end of each five-minute interval. This mode may be interrupted by a filter insertion of MODE 5 or a filter removal of MODE 6 if above 9 km altitude. It may also change into Modes 10 or 12 (see below).

MODE 7 is the close-up operation at descent below 6 km altitude. The pump is stopped, the valves and the probe cover will close and the system returns to Mode 2.

MODE 8 is a manual test mode entering from Mode 2 and is the normal mode for ground test and servicing allowing the GASP tester access to certain system functions for test and check-out.

MODE 9 is an automatic test mode which gives a ground display of a simulated path through the processor control program. It goes through Modes 1 - 7 but without activating all the system functions.

MODE 10 is the special routine for the acquisition of a grab sample where an actual air sample is collected in one of four bottles. It requires level flight at an altitude above 9.5 km and can happen only every third day. The bottle is purged for five minutes before sealing.

MODE 11 is a data control mode. In normal sampling (Mode 4) the processor will store all data from a data set-up and from calibration set-ups numbers one and two. This data can then be called up at ground check-out and a determination of the system health can be based on the operation at cruise altitude under actual pressure and temperature conditions.

DATA ACQUISITION AND SYSTEM CONTROL

Data Acquisition. (Cont'd)

MODE 12 creates a special record with one-hour long continuous recordings. The system will alternate a five-minute zero calibration set-up with ten minutes of normal data readings and will expose a paper filter every hour. This mode is entered only every third day above 11 km altitude.

MODES 13, 14 are not used and Mode 15 is a special program hold mode which allows complete system control in flight from a special panel. This mode was used for in-flight tests and during system development.

DATA AND DATA PROCESSING

Each 747 aircraft involved in the GASP project operated approximately 10 hours per day. The GASP system took a data point every 5 minutes above the 6 km minimum altitude. In some instances, the time between measurements may have extended to 10 minutes depending on whether calibration or status information was obtained at the 5-minute point. This means that data was taken approximately every 75 km and resulted in over 120 data points per day per 747. Additional data was supplied by the NASA-Ames Convair 990, when the GASP system was installed and operating.

Thus, large quantities of data were generated and several computer data processing steps were necessary. Individual aircraft were checked at average intervals of two weeks; at which time the cassette from the DAR was replaced.

The cassette contained all GASP data in raw form. This data could be divided into four types: (1) flight data including date, time aircraft position, altitude, heading, winds and accelerations; (2) status data on the identity and operational condition of particular flow system components and several measuring instruments; (3) system data including temperatures and pressures needed to calculate flow rates as well as verify proper system operation and (4) raw constituent data.

Once removed from the aircraft, the cassette was transcribed by United from cassettes/DAR format to a standard 9-track 1600 BPI computer reel. This standard computer reel was submitted to UAL Computer Services for initial computer processing, which took the raw data and reworked it into a format compatible with NASA-Lewis's computers (9 track 800 BPI). At this point, an engineering summary report was also generated, and used to verify proper GASP system operation on the aircraft.

DATA AND DATA PROCESSING

United delivered the 9-track 800BPI computer reel to NASA-Lewis for final data processing and further constituent analysis (Fig. 5). United utilized analyzed GASP data only to the extent it was necessary to monitor and maintain the GASP instrument system on the aircraft. Upon analysis of the 800BPI computer tape, NASA could also initiate maintenance actions to correct or replace malfunctioning GASP instruments and control units on individual aircraft.

MEASUREMENTS AND AIRBORNE INSTRUMENTS

The GASP in-situ measuring instruments, their basic operational principles, the range of the measurement and the associated NASA-Lewis Report references are given in Table 1. These instruments were basically commercial laboratory units which had been improved and modified by NASA to operate in a commercial aircraft environment. Such modifications included packaging the measuring instruments to airline specifications (both mechanically and electrically), testing for and elimination of any significant Electromagnetic interference (EMI) signals that may affect existing aircraft systems, and minimization of instrument package weights for ease of handling and fuel efficiency. Instrument sensitivities were significantly raised by NASA so that the units could measure the very low concentrations in the upper atmosphere.

United's task was to integrate these instruments with these data acquisition and system control units and supply all the support wiring and aircraft interconnects. NASA supplied the intra-measurement unit plumbing harness (Ref. 4), the Flow Control Unit (Ref. 2), the Transducer Case (Ref. 5), and the Pump Package (Ref. 6), which raised the air sample to 1 ATM for those measuring instruments that could not perform at less than one atmosphere.

Although real-time, in-situ measurements of atmospheric constituents were preferred, several species required laboratory analysis of collected samples because of their complexity. Instrument packages could not be designed to measure these species and filter paper was used to collect small particles for sulfate and nitrate concentration analysis. In addition, one liter stainless steel bottles were exposed at altitude to "grab" whole air samples collected during flight.

Two versions of the filter mechanism were utilized during the lifetime of the GASP project. A single-filter mechanism (Ref. 7) was originally installed on two of the 747's, exposing a single IPC cellulose fiber filter to the sample airflow. Filter exposure time was recorded by the data acquisition system and the filter was replaced at regular intervals, sealed in a clean-room quality bag, and returned to NASA-Lewis for laboratory analysis.

MEASUREMENTS AND AIRBORNE INSTRUMENTS (Cont'd)

An improved multi-filter mechanism was developed in 1977. The new unit replaced the single filter cartridge with an eight-cartridge filter magazine, which operated in a manner similar to a slide projector (Ref. 8).

The sample bottle unit employed four one-liter stainless steel bottles with integrated seal-off valves and plumbing, which opened sequentially to take samples of air at altitude. The exposed bottles were returned to NASA-Ames for analysis and it was designed mainly for chlorofluoromethane monitoring.

MAINTENANCE AND SERVICING

Much effort was spent on designing a system that could be maintained and serviced in an airline operational environment, and, at the same time, assure a high level of confidence in the collected data. The optimum design servicing interval was set at 14 days. However, given variations in normal aircraft schedules, this service interval could change from 10 to 21 days. Therefore, depletable components such as tape cassettes, sample bottles and distilled water had to last a minimum of 21 days between service intervals.

Maintenance Organization. As mentioned earlier in this report, the GASP program could not depend upon the usual airline maintenance organization for supporting GASP - outfitted aircraft. A separate, dedicated maintenance organization had to be constructed within the normal airline framework that would coordinate GASP activities at each of the three major GASP stations: San Francisco, (SFO), New York, (JFK), and Sydney, Australia (SYD).

Three United Airlines engineers at San Francisco were assigned to the GASP program and became the core of the Maintenance Organization. They served as the interface between the subcontractors (Pan Am and Qantas), and the NASA-Lewis GASP office, and the outside instrument vendors. In addition, United controlled the logistics of spare parts and other GASP related material.

Pan Am assigned two engineers to support GASP and Qantas supplied an engineer and a maintenance specialist. All the GASP personnel subsequently directed and supervised regular airline personnel as necessary to accomplish servicing on any of the GASP aircraft. Pan Am and Qantas worked with United through their San Francisco offices as well as directly from New York and Sydney to coordinate GASP aircraft activities and the movement of GASP materials.

MAINTENANCE AND SERVICING

Maintenance Organization. (Cont'd)

In general, Pan Am at New York handled both Pan Am and United GASP B747's while United handled all GASP aircraft in San Francisco. Qantas in Sidney serviced both Pan Am's 747's and their own. United had the additional responsibility of working with NASA-Ames and supporting their Convair 990 in GASP related matters (Fig. 6).

Reports on the individual GASP aircraft and the status of open maintenance items and of spare parts were published and tele-metered at the end of each week to each airline and NASA-Lewis. At approximately monthly intervals, NASA-Lewis hosted a maintenance conference at Cleveland to review technological progress and discuss items important to operating GASP. Due to the long distances involved, Qantas could only attend two of the monthly conferences per year; Pan Am and United attended regularly.

Maintenance and service requirements on the GASP project can be divided into four areas: (1) Routine Service, (2) Flow System evaluation, (3) Ozone Destruction Test; and (4) Unit of Instrument Overhaul. Each area will be discussed separately.

Routine Service. Routine servicing of the on-board GASP system was provided by a bi-weekly health check on the individual aircraft.

The health check recorded the condition of the GASP system as it arrived at the airport/station; identified potential defects in either the control or the constituent measurement systems; and provided for the replenishment of items such as tape cassettes, filters, and distilled water. Step-by-step instructions were followed during the checkout and troubleshooting and were detailed in a "GASP Operations and Maintenance Manual." (Ref. 9).

A special carry-on tester box aided in the health check. Once attached to the GASP system interface/distribution panel on the aircraft, the tester could automatically run the computer-processor (DMCU) through its paces and verify all proper command sequences. The engineer/technician monitored the tester by viewing sequentially activated lights. Problems were highlighted by improper lighting sequences or, in the case of major component failure, red warning lights. One mode in the tester allowed the GASP operator to take manual control of the tester for detailed testing and improvised troubleshooting. Once proper DMCU control had been verified, the next step in the health check was to check the credibility of the data by comparing known operational limits to the data which the GASP system had actually recorded in the so-called Sample Frame.

MAINTENANCE AND SERVICING

Routine Service. (Cont'd)

The Sample Frame consisted of the last complete set of data and status information taken at sampling altitude in the preceding flight. It was taken out of the DMCU memory and displayed on command onto the tester.

By completing the GASP Service Check Sheet (Fig. 7), the engineer/technician compared data from the Sample Frame to design limits. If the Sample Frame data was outside the limits indicated on the Service Check Sheet, further investigation of the GASP system was performed and discrepancies corrected; usually by unit replacement.

The final step in the health check was to replace the tape cassette with a fresh one and to replenish expended supplies such as filters or the distilled water used in the Condensation Nuclei instrument.

If the health check revealed problems connected with the air-flow control of sample pressurization system, defective units were replaced as necessary and an additional GASP flow system test was performed.

Flow System Test. To completely troubleshoot the GASP flow system on the ground, a vacuum pump was required. This small carry-on unit simulated pressures corresponding to an altitude of 10.7 km by drawing cabin air through the pressurized system. Three special test valves in the flow control unit (controlled by the tester) directed the test airflow. Leaks, which accounted for the majority of the flow control problems, could be detected when as low as 0.03 litres per minute. By following the detailed instructions of the troubleshooting procedures, specific malfunctioning flow control units or constituent measuring instruments could be identified. (Ref. 9)

Ozone Destruction Test. At approximately six-month intervals, whenever the aircraft was scheduled for an overnight maintenance visit at a conveniently located airport, an ozone destruction test was performed. This test determined the percentage of ozone loss due to wall and thermal effects of the GASP plumbing and pressurization system. The ozone loss figure varied from 1.5 to 6.5% depending on the condition of the teflon-lined ozone lines and pump diaphragm and was used to correct the ozone data taken during the preceding 6-month period.

The ozone destruction test kit, which was NASA designed, consisted of two large suitcases and included a small, carry-on vacuum/supply air pump; a special plumbing harness; several special boxes which interfaced the ozone destruct plumbing harness to the on-board GASP system and provided corrective pressure data during the ozone test; and a display-control unit which

MAINTENANCE AND SERVICING

Routine Service. (Cont'd)

provided the readings for pressure, air flow, and ozone levels to the operator.

Varied, but known, levels of ozone were injected into the GASP inlet of the aircraft. Measurements were then taken at the ozone constituent instrument and the resulting differences (ozone loss) were plotted. By analyzing the plot, an ozone loss figure (expressed as percentage of correction) was calculated and subsequently used to correct the aircraft ozone data.

Unit Overhaul. Initially NASA-Lewis was the focal point of all constituent measuring and air flow unit repairs and overhauls. Whenever a GASP unit malfunctioned, it was sent to NASA-Lewis for evaluation and repairs. NASA, in turn, would either affect repairs itself or redistribute the non-functional unit to the original instrument manufacturer for overhaul.

This soon became a highly expensive and time-consuming effort. Delays in spare parts ordering and a lack of an on-hand spare parts pool prevented the expeditious repair of GASP units. Interface difficulties between GASP and instrument manufacturers and the manufacturer's long turn-around repair times also hampered the program's logistics. Therefore, NASA-Lewis contracted with United to provide maintenance on the following GASP units: (1) Flow Control Unit, (2) Transducer Case, (3) Pump Package, (4) Particle Sensor, (5) Ozone Instrument, (6) DMCU, (7) Data Acquisition Recorder (DAR), (8) FDAU, and (9) Clock-Calendar Unit. Because United already maintained items (6) - (9), the only additional unit overhauled were items (1) - (5).

A dedicated shop area was created and named the GASP Accessories Overhaul Lab (GAOL). NASA supplied the basic test equipment, the maintenance manuals, and the initial overhaul training. United provided the mechanic manpower, the facilities, and its airline expertise in logistics and maintenance.

If one of the above-mentioned units malfunctioned on a GASP 747, the respective airline engineer would replace the defective unit with an available on-site spare, if possible, and ship the disabled GASP unit to San Francisco via internal airline air-freight with a copy of the GASP service check sheet to aid the GOAL technician's troubleshooting. Once repaired to NASA specification, the GASP unit was replaced into the spares pool and, if necessary, shipped to either New York, (Pan Am) or Sydney, (Qantas), to maintain the on-site spares pool.

Because of the distance and long turn around times involved, the Qantas spareparts pool was stocked with at least one spare unit of each GASP component whenever feasible. The Pan Am spares pool was likewise provisioned; however, because New York could

MAINTENANCE AND SERVICING

Routine Service. (Cont'd)

be reached by air freight in less than 10 hours from San Francisco, choices of where to send spare units usually weighed toward Sydney. United engineers were constantly aware of the changing priorities involved in administering the GASP program and special arrangements were made to support any unusual GASP assignments. (Ref. 22).

Control and analysis of unit failure were reported by using a standard failure form, NASA form C-8192 (Fig. 8), and the management information needed to track the over 175 different, individual GASP control and measurement instruments rested with a computer program developed by United. This computer program provided the chronological history of individual GASP units and of individual GASP aircraft systems along with a listing of existing unit location (i.e. in particular aircraft, at particular on-site spare pools, or in particular repair shops). The management program was updated at approximately monthly intervals.

Unit maintenance improved noticeably after the GAOL was established and functioning. The primary benefit was the large reduction in unit turnaround from the initial reported malfunction to the re-entry of the unit into the spares pool. By eliminating the extra transit time between the airlines and NASA, and NASA and the outside vendor, the GAOL reduced unit turnaround from as much as 6 months to an average of 14 days. Thus, added spare units and instruments were neither needed nor ordered, and a subsequent overall cost savings in the GASP program achieved.

Additional cost savings were realized in the GAOL when it was discovered that certain standard airline parts could be substituted for vendor supplied items such as bolts, nuts, pins, bearings and airline-standard lubricants. Replacing industrial quality parts with aircraft quality parts provided extended service as well as, in some cases, costing less in initial purchase.

All GASP units were maintained to NASA specifications. Likewise, all GAOL test equipment was periodically calibrated, per NASA directions. For example, at each overhaul or maintenance visit, the aircraft ozone monitor was checked against a secondary transfer standard. This standard was a laboratory-type ultraviolet photometer which was initially calibrated and adjusted using a one-percent neutral buffered potassium iodide (KI) method. Later in the GASP program, the standard was calibrated at the Cal Tech Jet Propulsion Laboratory (JPL) using their five meter UV photometer. The laboratory secondary transfer standard was recertified at approximately six-month intervals and, as a result, the ten-flight ozone instruments were stable to within one percent during one year of operation.

RESULTS AND RECOMMENDATIONS

As conceived in feasibility studies and as designed, installed, and maintained by NASA and the airlines, the GASP system successfully integrated different levels of instrument technology under a common commercial airline environment. Significant modifications to both instruments and the B747 necessitated meeting certain certification requirements and obtaining a FAA Supplemental Type Certificate (STC) of airworthiness. (Ref. 9).

Between December 1974 and July 1979, the four B747's operated by United, Pan Am, and Qantas collected data for a total of 5,289 days. Over 400 transcribed data tapes were created and transmitted to NASA-Lewis for analysis. NASA-Lewis, in turn, collated the tapes and published formal reports on their contents. (Ref. 11-21).

Several major points, which have not been covered above, need to be itemized as an aid to future programs of this scope. First a program such as GASP, which involved three airlines in three different areas of the world, required three central locations as focal points of maintenance and engineering coordination. In the case of GASP, these were New York (Pan Am), San Francisco (United), and Sydney, Australia (Qantas). Within each center, a separate storage area, accessible only to GASP personnel, was acquired and this proved the most economical and efficient means to quickly support GASP aircraft maintenance visits. These storage areas were generally independent of the regular airline stores operation, although labor union contracts had to be followed in matters such as unit transport.

Because the storage area, the GASP engineer's desk or office, and the GASP aircraft could be in widely spaced geographic locations, a leased van was procured in some GASP offices to reduce transit times. The van also served as a mobile parts emporium, which could be stocked with all necessary space parts, test equipment, and special tools. The van proved its worth on many occasions, especially in the San Francisco GASP office where the engineers supported both the airport location and the NASA-Ames Convair 990 program at Moffet Field in Mt. View, which is 50 km. south of San Francisco International Airport.

Finally, during the time span of the GASP it was necessary to revise the software of the DMCU processor as more instruments were added to the GASP installation or as changes were made in the GASP sampling priorities. Almost all of these changes were developed, debugged, and issued by the DMCU vendor after meetings with NASA scientists or UAL engineers. However, the process was time consuming and delays of several months were not uncommon between the inception of a software change and its actual implementation. A large portion of the delays were due to programmer turnover at the DMCU vendor.

RESULTS AND RECOMMENDATIONS (Cont'd)

Training an individual(s) at NASA or United directly involved in the GASP system would have greatly alleviated such software delays. However, due to GASP project budgetary limitations, such training was not accomplished. The investment for software maintenance that could have been made at the program's beginnings would have provided better continuity in software development and reduced delays due to re-educating new programmers unfamiliar with the GASP system.

PAN AM 747SP FIFTIETH ANNIVERSARY FLIGHT

One of the great successes in the GASP program was obtained when Pan Am celebrated its 50th anniversary by flying around the world on a polar route in 54 hours. The GASP system 747SP was selected as the aircraft to make this historic flight which began October 28, 1977. The route started in San Francisco, went over the North Pole to London, continued to Capetown, South Africa, over the South Pole to Auckland, New Zealand, and then back to San Francisco, arriving October 31, 1977. Three two-hour fuel stops were made in London, Capetown, and Auckland.

The normal GASP data acquisition system software, which records data for 16 seconds at the end of each five-minute flight segment, was specially altered to record data continuously whenever the aircraft was above 6 km in altitude. Ozone values were updated each 20 seconds and Carbon Monoxide and Condensation Nuclei information updated each second.

All collected data exhibited latitudinal and hemispheric differences over the 54-hour flight. (Ref. 22).

CONCLUSIONS

Using commercial airliners as an instrument platform to sample and monitor the atmosphere between 6 and 12 km provided an extensive, continuous, and economical means of global data acquisition. A considerable design effort, extending the range of existing constituent measuring equipment and integrating this equipment into the installation and operational constraints imposed by commercial airlines, made such an approach a reality on B747 aircraft. The result was an automated, unattended atmospheric constituent measuring system.

Techniques for insuring the quality of the data collected were established by in-flight checks and frequent calibrations. Maintenance and Servicing procedures were set up to assure confidence in the collected data.

CONCLUSIONS (Cont'd)

In total, the data-collecting system was installed and maintained on four B747 and on one Convair 990. Over fourteen aircraft operating years of data were recorded in more than 400 computer tapes.

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TABLE 1.

<u>GASP MEASURING INSTRUMENTS</u>			
<u>CONSTITUENT</u>	<u>METHOD</u>	<u>RANGE</u>	<u>NASA-LEWIS TEST SUMMARY REPORT #</u>
Ozone	Ultraviolet Absorption Photometer	3ppb to 20ppm (parts per billion/million)	
Water Vapor	Cooled Mirror Hygrometer (Latest Version)	Dew/Frost Point -80° to +20°C	0-100-BZ
	Aluminum Oxide Hygrometer (Original Version)	Dew/Frost Point -100°C to +40°C	0-020-BZ
Carbon Monoxide	Infrared Absorption Analyzer	0.02 to 1ppm	0-030-BZ
Nitric Oxide	Chemiluminescent Analyzer	0.05 to 10ppb	
Particles (Dia. 70.3 μM)	Light Scattering Sensor	---	0-040-BZ
Condensation Nuclei	Cloud Chamber	Min. Concentration 10/CM ³	0-070-BZ

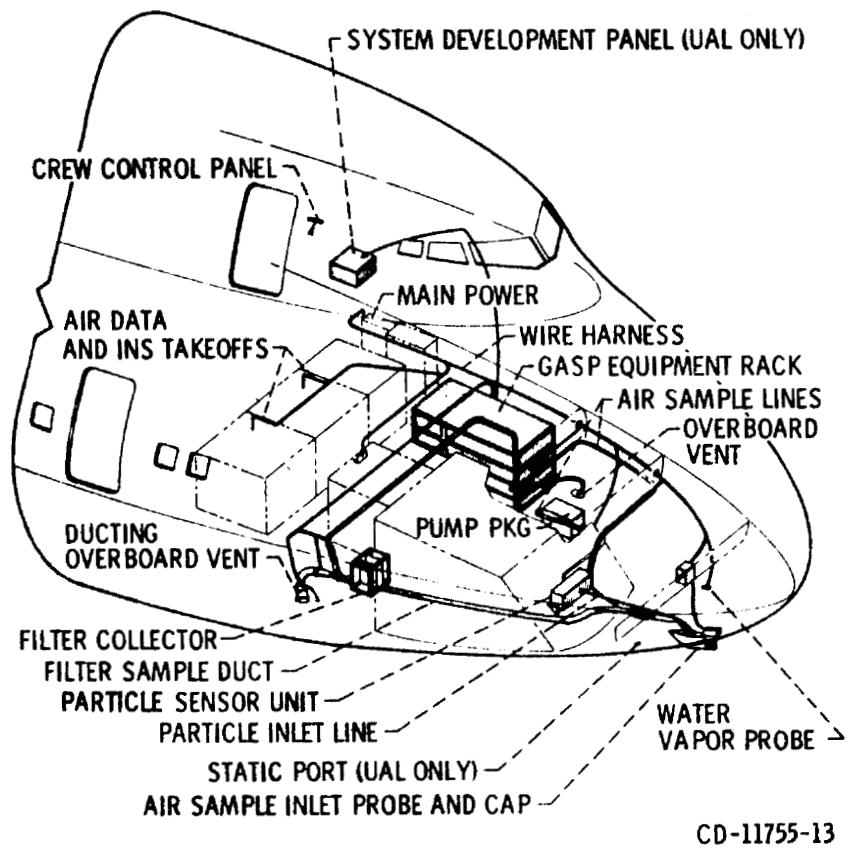


Figure 1 - GASP system installation on 747.

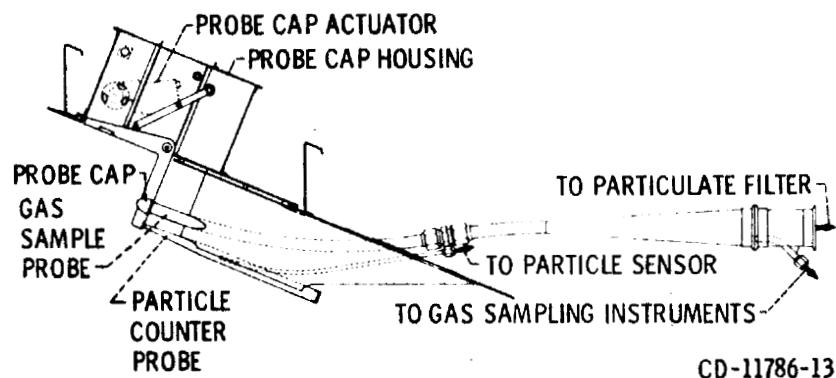


Figure 2 - Dual GASP air sampling probe on 747 installations

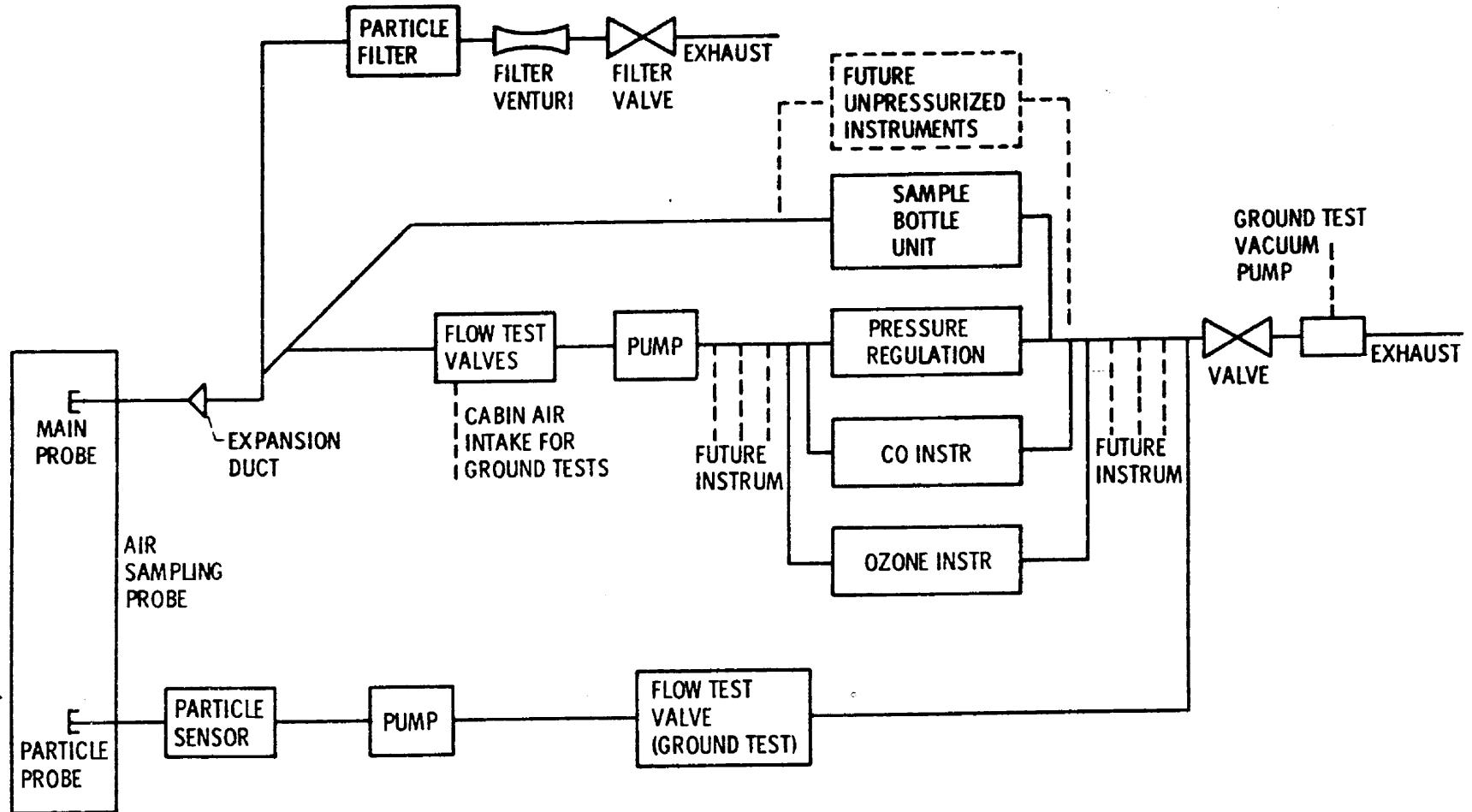


Figure 3 - Simplified GASP air sample flow system diagram.

ELECTRONIC/ELECTRICAL DESIGN

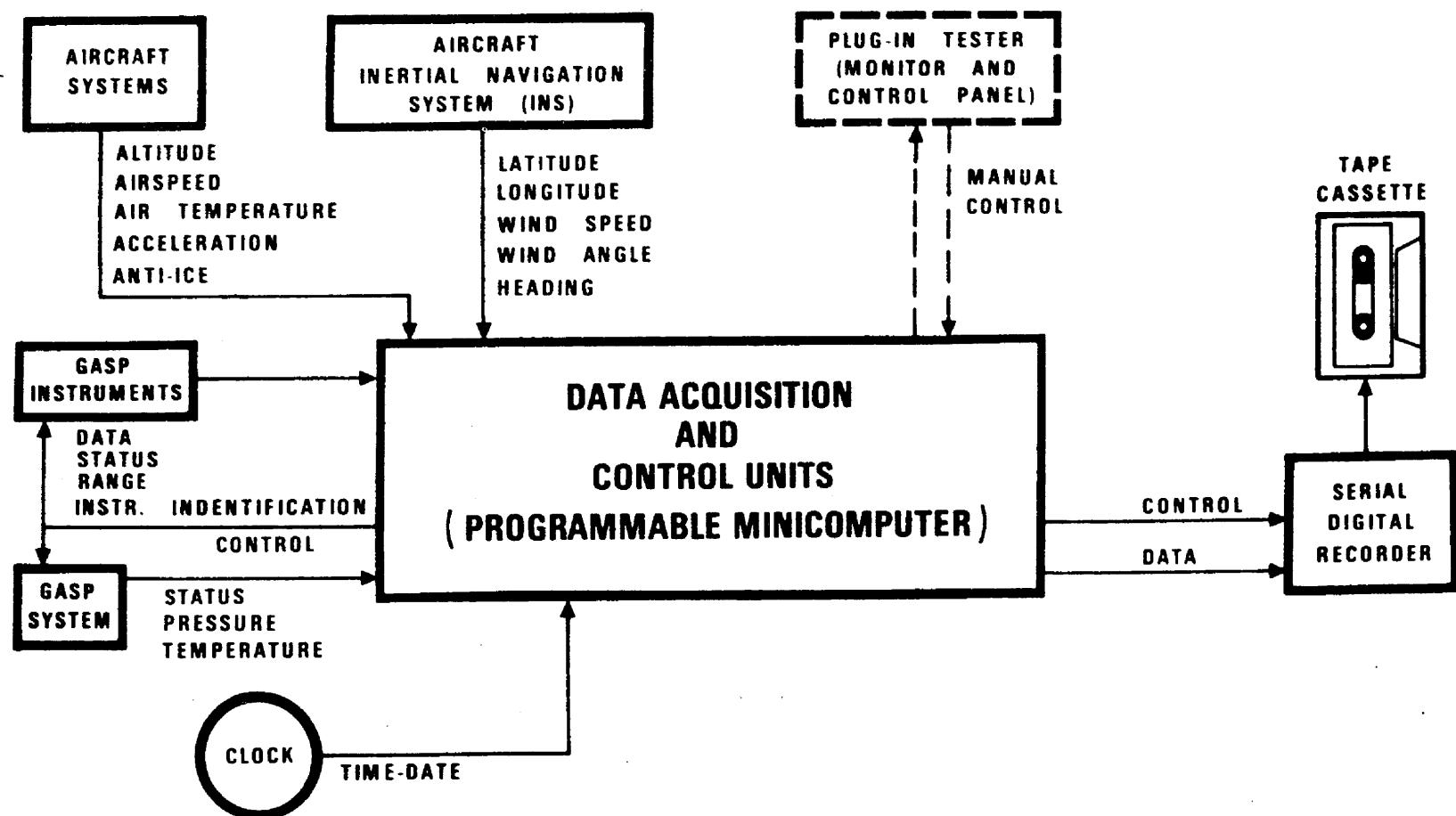


Figure 4 - Simplified GASP Data Acquisition and System Control Diagram.

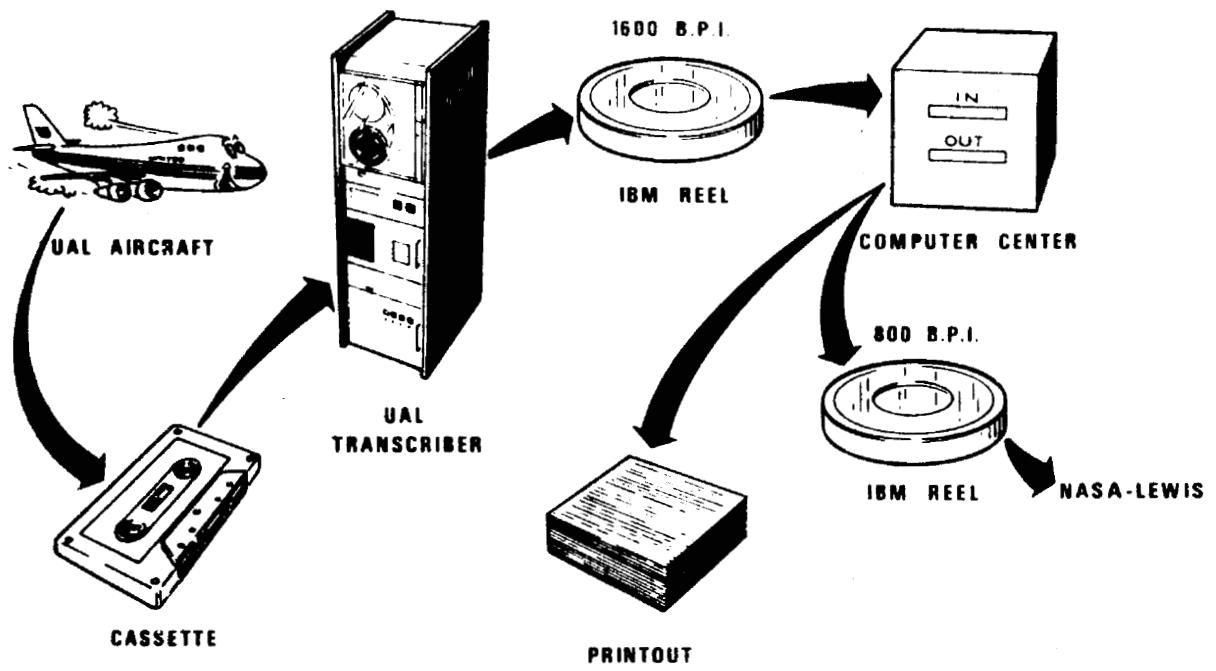
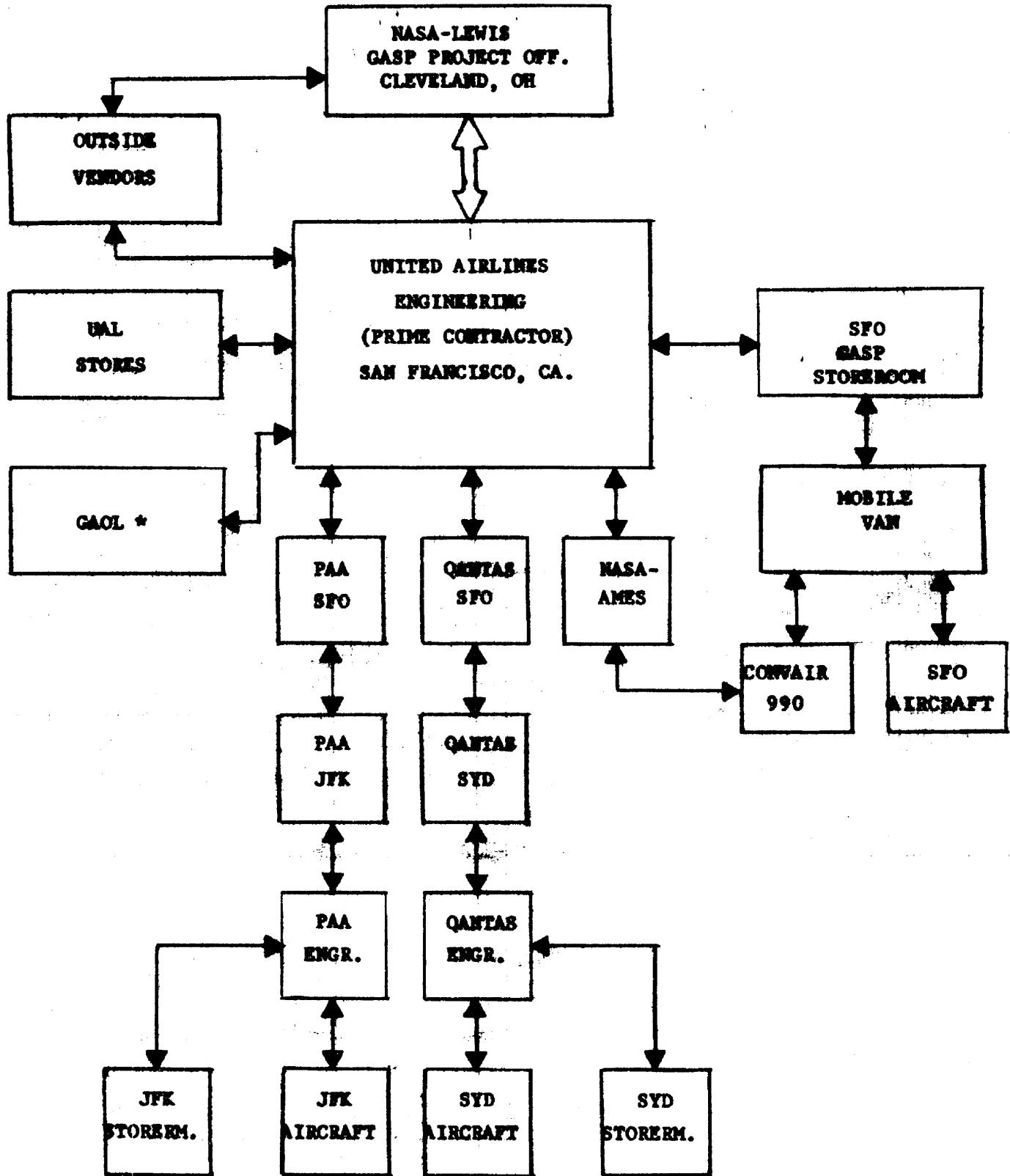


Figure 5 - Data Processing Flow



* GASP ACCESSORIES OVERHAUL LABORATORY

FIGURE 6 GASP MAINTENANCE INTERFACES

AIRPLANE: _____ DATE: _____ LOCAL MO DAY YR TIME: _____ LOCAL STA: _____ BY: _____

NUMBER CHECK	VALUE	SHOULD BE	OK	NUMBER PAGER	NUMBER CHECK	VALUE	SHOULD BE	OK
2. 1 WALK-AROUND, C/BENK	X	OK		9. b 38 CN VALVE MOTORS		X	NOISY	
3. 2 START-UP/INOPS	X	OK		9. d 39 CN CAL "OFF"	1/09	---	0000-1320	
4. 3 AUTOTEST - AS DESCR. DATA ACA	X	OK		9. d 40 CN CAL 1	1/09	---	3150-5450	
5. b 4 SYNCHRONOCS 0/01	X	7044,0732 7045,0738		9. d 41 CN CAL "OFF"	1/09	---	RETURNS TO 0008-1320	
5. c 5 TIME/GMT 3/37 1/57	--	--		9. d 42 CN RESO. TEST		X	CYCLES	
5. e 6 FILTER N. 6 1/36	xxx	--		9. e 43 CN WATER LEVEL		X	FILLED	
5. d 7 DAY NO 2/36	--	--		10. a 44 GMT DISPLAYED		---	---	
5. f 8 SAMPLE BOTTLE 1/55	--	20010		10. d 45 DAY DISPLAYED ANTI-ICE		---	---	
	TAKE S.F. DATA BOTTLE	X	-	11. c 46 SCOOP HTR TEST		—A	1.0±0.5A	
8. b 30 OZONE, CAL 3 1/48	--	200		11. d 47 PROBING HTR TEST FILTER		—A	2.0±0.5A	
8. b 31	4/49	--c	X58	12. c 48 NEW FILTER PACK 2/17		—Z	—	
8. b 32	4/38	--	200	12. c 49 NEW FILTER N. 1/36	--Z	—	—	
8. b 33	4/39	--c	X58	14. c 50 DMU DAR TEST	X	OK		
8. c 34 OZONE, CAL 2 4/49	--c	X33-X48		14. c 51 FRAME CT. 3/23		---	RESET	
8. c 35	4/39	--c	X33-X48	52				
8. d 36 OZONE, CAL 4 4/49	--c	>X20/X>3		53				
8. d 37	4/39	--c	>X20/X>3	15 54 ALL C/8'S CHECKED		X	DONE	

CODING: C - BCD, B - OCTAL, OTHERWISE DECIMAL, X - DISREGARD

FIGURE 7A - GASP CHECK SHEET, PAGE 1.

NASA/VAL GLOBAL AIR SAMPLING PROGRAM (GASP)
GASP SERVICE CHECK SHEET 2

AIRPLANE: _____ DATE: _____ TIME: _____ STA: _____ BY: _____
 LOCAL mo day yr LOCAL

SAMPLE FRAME DATA			N		CAL 1		CAL 2	
MANUAL EACH	No.	CHECK	VALUE	SHOULD BE OK	VALUE	SHOULD BE OK	VALUE	SHOULD BE OK
6.e	9	DISPLAY AS DESCRIBED		OK		OK		OK
6.c	10	SF RECORD CT 4/55	---	x	---	x	---	x
6.d	11	SF CONNSECT ALT 1/23	---	x	---	x	---	x
6.e	12	CO PRESS 2/23	5430-7000	---	<N	---	<N	
6.e	13	OZONE PRESS 2/62	5430-7000	---	<N	---	x	
6.e	14	MANIFOLD PRESS 1/62	6700-7720	---	N ± 100	---	N ± 100	
6.c	15	PARTICLE CTR FLOW 1/60	<2330	—	x	—	x	
6.c	16	FILTER VENTURI IN 2/60	<2540 <7000(635)	—	x	—	x	
6.e	17	FILTER VENTURI TH 3/60	<2000 <7000(531)	—	x	—	x	
6.e	18	CN PRESS 2/60	1500-3300	—	x	—	x	
6.e	19	CABIN PRESS 4/23	<7000	—	x	—	x	
6.e	20	NO _x (CAB O ₃) PRESS 1/35	<7000	—	x	—	x	
6.f	21a	OZONE DATA + 4/49	—	x	—	x9900x00	—	x33-x48
6.f	21b	OZONE DATA 4/48	—	x	—	970-010	—	x
6.f	21c	CAB. O ₃ DATA + 4/39	—	x	—	x99 00x00	—	x33-x48
6.f	21d	CAB O ₃ DATA 4/38	—	x	—	970-010	—	x
6.g	22	CO BITE, DATA 1/28	2300-5450	—	0100-4600	—	C3 + 3715 ± 10% —	
6.i.	23	DF PT 1/12	>4600	—	x	—	x	
6.j	24	CN BITE, DATA 1/09	—	—	3M0-5850	—	0001-1320	
6.l.	25	PART BITE 1/09,06,08,20,22	—	FIRST BCD 9's	—	x	—	x
6.m	26	VERTICAL ACCEL 1/02	3435-3714	—	x	—	x	
6.m	27	SF GMT 3/37 NR 1/37 MIN	—	x	—	x	—	x
6.m	28	SF DAY 2/36	—	—	—	—	—	
6.o	29	SF MANUAL RECORD	x	DONE	x	DONE	x	DONE

CODING: C - BCD, 8 - OCTAL, OTHERWISE DECIMAL

* BITE: LAST DIGIT SHALL BE 0 OR 4

FIGURE 7B - GASP CHECK SHEET ,PAGE 2.

FAILURE REPORT AND ANALYSIS (See instructions on reverse side.)					1. REPORT NO. UAL
2. PROJECT (Name) GASP					3. PROJECT NO. YOD4567
SECTION I - REPORT OF FAILURE					
4. NAME OF PART OR ASSEMBLY		5. VENDOR (or manufacturer)			
6. STATUS <input type="checkbox"/> EXPERIMENTAL <input type="checkbox"/> PROTOTYPE <input type="checkbox"/> FLIGHT		7. PART OR MODEL NO. ON BOARD	8. SERIAL NO. GASP MANUAL		
11. PRIOR HISTORY					
12. DESCRIPTION OF FAILURE (Test conditions, difficulties, symptoms, point of failure, etc.)					
13. PLACE OF FAILURE		14. DATE & TIME OF FAIL.	15. OPERATING TIME TO FAILURE	16. PERSON REPORTING FAILURE (Sign.)	
17. PART OR PARTS RESPONSIBLE FOR FAILURE		18. CLASS OF FAILURE <input type="checkbox"/> CRITICAL <input type="checkbox"/> MINOR <input type="checkbox"/> REPETITIVE <input type="checkbox"/> MAJOR <input type="checkbox"/> SECONDARY			
19. EFFECT ON SYSTEM PERFORMANCE					
20. ANALYSIS					
21. PERSON MAKING ANALYSIS (Signature)		22. ORG. CODE/NAME EG	23. DATE	24. DISPOSITION OF FAILED PART(S) <input type="checkbox"/> REPAIR <input type="checkbox"/> SCRAP <input type="checkbox"/> OTHER	
SECTION III - CORRECTIVE ACTION					
25. RECOMMENDATIONS (Continue on reverse, if necessary)					
26. PERSON MAKING RECOMMENDATION (Signature and date)		27. ORGANIZATION (Name or code) EG		28. EFFECTIVE DATE	
SECTION IV - DISTRIBUTION AND CONCURRENCES					
TO PROJ. OFFICE	SIGNATURE	DATE	TO	SIGNATURE	DATE
PROJ. ENG.					
OR & QA					